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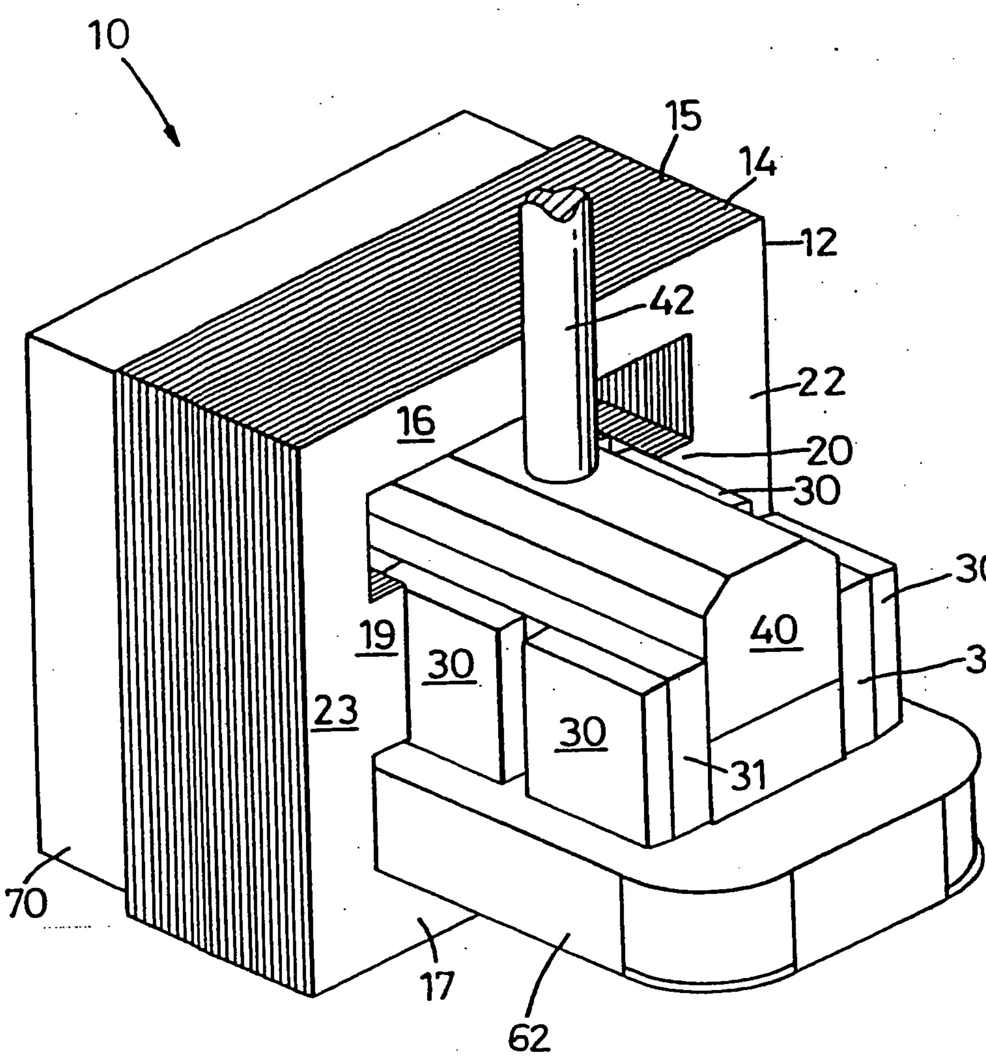

Fig. 1

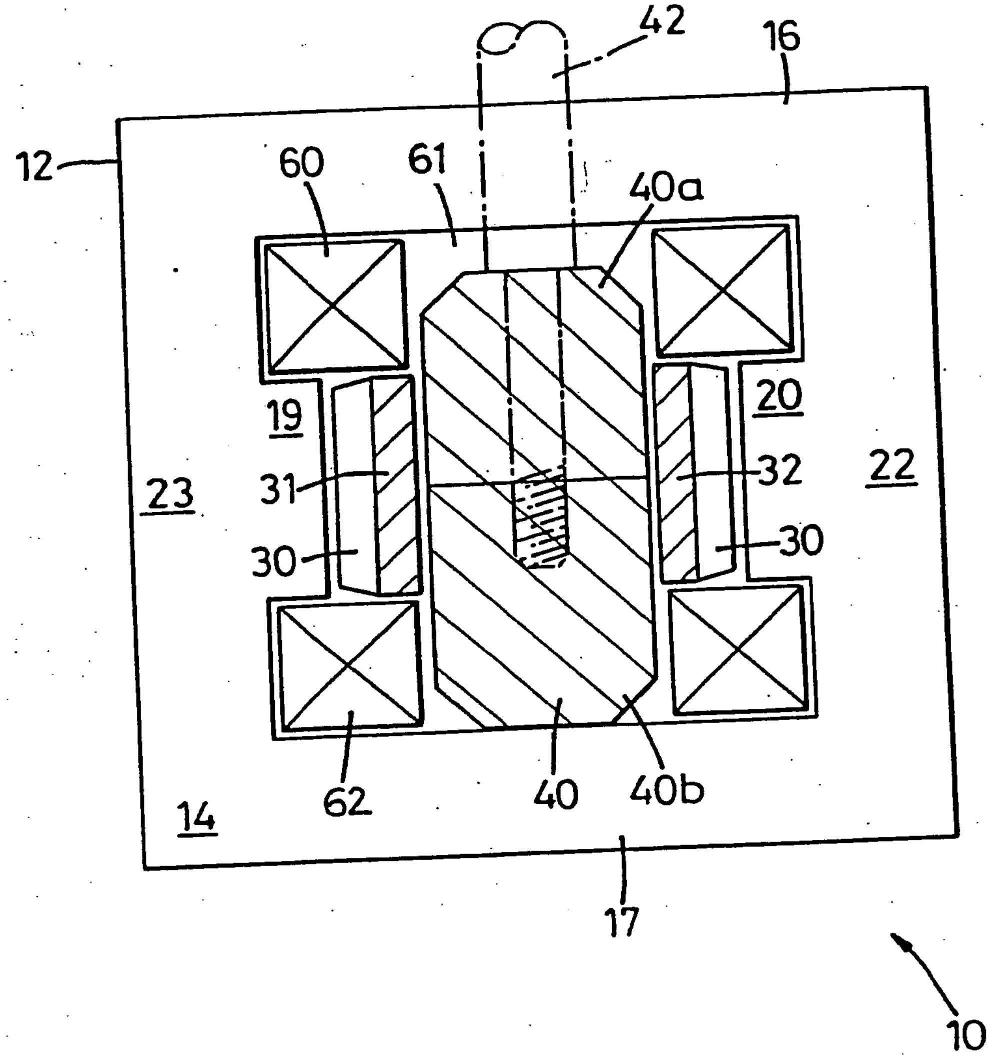

Fig. 2

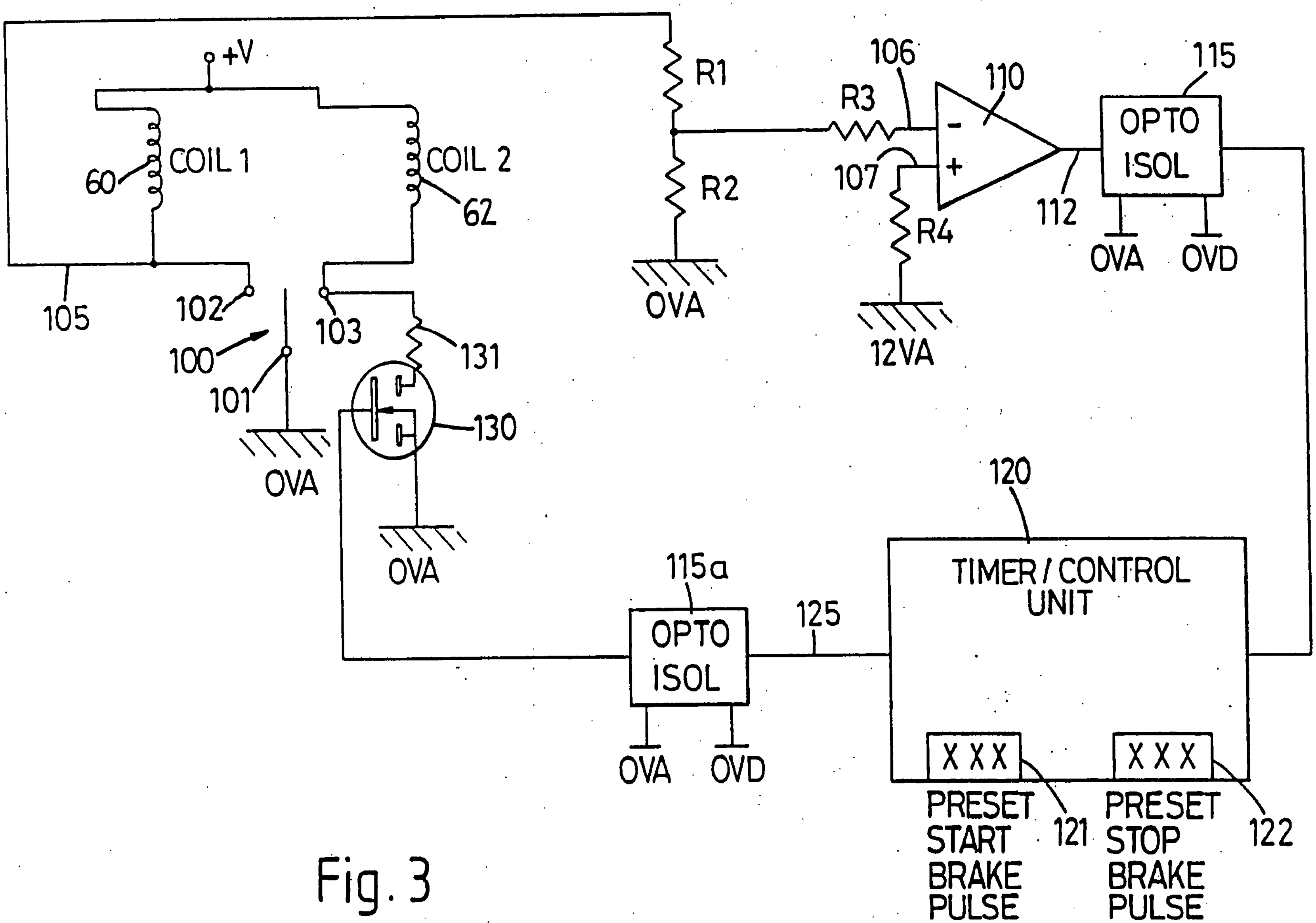
+V
COIL 1
60
COIL 2
62
105
102
103
100
101
131
130
OVA
OVA
R1
R2
OVA
R3
106
110
107
R4
12VA
112
115
OPTO ISOL
OVA
OVD
120
TIMER / CONTROL UNIT
115a
OPTO ISOL
125
OVA
OVD
X X X
X X X
PRESET START BRAKE PULSE
121
PRESET STOP BRAKE PULSE
122

Fig. 3

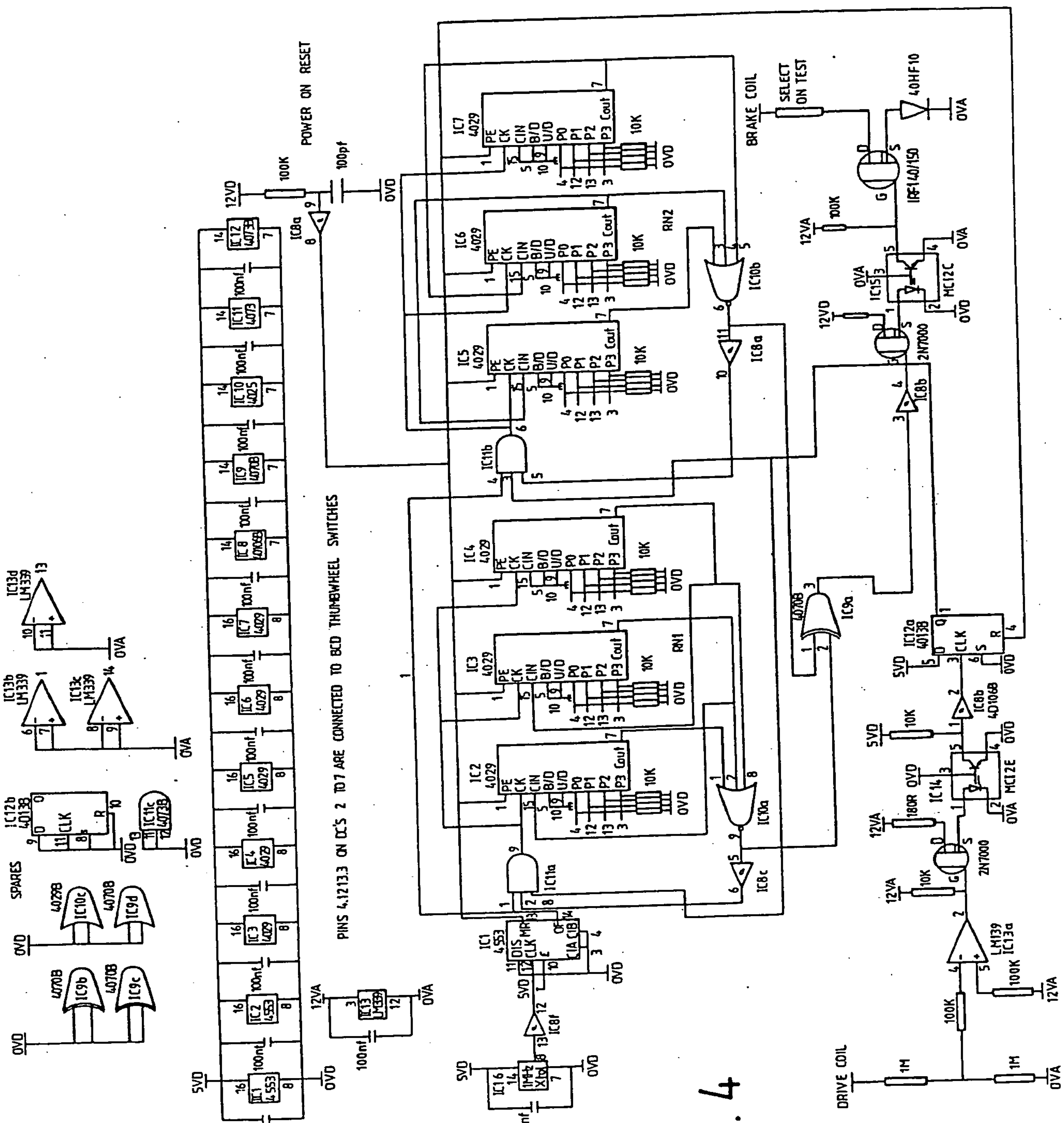
POWER ON RESET
BRAKE COIL
SELECT ON TEST
DRIVE COIL
PINS 4,12,13,3 ON IC'S 2 TO 7 ARE CONNECTED TO BCD THUMBWHEEL SWITCHES
SPARES
IRF140/150
40HF10
2N7000
MC12C
MC12E
RN1
RN2

Fig. 4

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IMPROVEMENTS IN AND RELATING TO PERMANENT MAGNET BISTABLE ACTUATORS

The present invention relates to magnetic actuators, and in particular to actuators suitable for the operation of electric circuit breakers.

In PCT application number PCT/GB94/01975 there is described a permanent magnet, bistable magnetic actuator which includes a pair of coils, one of which is used to "flip" the actuator to one of its bistable positions, and the other of which is used to flip the actuator to the other one of its bistable positions. Each one of the coils is thus used to overcome permanent magnet flux circulating in the yoke holding an armature in one of the actuator's bistable positions.

With reference to figures 1 and 2, such an actuator is described. A bistable, permanent magnet actuator according to the prior art is shown generally as 10. The actuator comprises an outer yoke 12, which is composed of a number of laminations 14, 15 formed of a suitably high magnetic permeability material, for example steel sheets. Each lamination has an upper and a lower pole portion 16, 17 and preferably includes a pair of centre arms 19, 20 projecting inwards from side portions 22, 23.

Within the laminations 14, 15 of yoke 12, lying between and adjacent to centre arms 19, 20 are a number of permanent magnets 30. Magnets 30 are attached to a pair of inner yokes 31, 32 which are spaced from an armature 40 which is reciprocally mounted within the assembly in order that it may slide between a first, lower position in which the lower face of the armature 40 is in contact with the lower pole portion 17 of yoke 12 as shown in figure 2, and a second upper position in which the armature is in contact with the

upper pole portion 16 of yoke 12. Coaxial with the armature 40 is an actuator rod 42 shown in dotted outline on figure 2.

A pair of coils 60, 62 circumscribe the upper and lower portions of armature 40 respectively. The coils are preferably mounted within the recesses formed between the poles 16, 17 of the yoke 12 and the centre arms 19, 20.

With the armature 40 in the position as shown in the figures, a low reluctance magnetic circuit is formed by the magnet 30, the lower half of side portion 22 of yoke 12, the lower pole 17 of yoke 12, the lower half of armature 40 and the inner yoke 32. A high reluctance magnetic circuit is formed by magnet 30, the upper half of side portion 22 of yoke 12, the upper pole 16 of yoke 12, the upper half of armature 40 and the inner yoke 32. Corresponding circuits are replicated on the left half of the actuator as viewed in figure 2.

In this position, a strong permanent magnet flux is present in the low reluctance circuit which holds the armature in the lower position. Little flux is present in the high reluctance circuit due to the air gap 61 present between the upper part of the armature 40 and the upper pole 16 of the yoke 12. However, it will be recognized that the temporary application of a current of appropriate polarity in upper coil 60 will cause a high flux to be forced across the air gap 61, providing an upward motive force on armature 40 in order to close the air gap. Providing the flux induced by coil 60 is greater than the flux present in the low reluctance circuit, the armature will be "flipped" to an upper position, thus swapping over the high and low reluctance circuits described *supra*.

The armature may be returned to its first bistable position by analogous use of the lower coil 62.

This actuator is suitable for use in a large number of applications, including that of switching circuit breakers. One of the problems associated with this type of actuator is the lack of control over various parameters of its operation, such as the speed and length of stroke, and driving force of the actuator. Although the prior art device is designed to be readily manufactured in easily variable configurations, to suit different applications, each actuator specification is fixed and cannot be varied once constructed.

In PCT application number PCT/GB95/00347 there is described a sequential isolating circuit breaker. In this device, a vacuum interrupter and sequential isolator are electrically connected in series. A small gap, fast acting, vacuum interrupter provides the make and break actions of the circuit breaker, and a large gap, slower acting, off-load isolator provides an additional element of safety by introducing a large isolation gap after the vacuum interrupter has interrupted the current. Such dual action circuit breakers are considered to be essential when dealing with high voltage systems. PCT/GB95/00347 teaches an actuator system which enables a two-phase operation to take place using a single actuator — a short, rapid stroke to open or close the vacuum interrupter, and a longer, slower stroke open or close the isolator, sequential to one another. However, this is achieved with a quite complex mechanical arrangement with the consequent implications to cost of manufacture and reliability that such complex arrangements entail. In addition, there are some gap / stroke length combinations which would be difficult, if not impossible to achieve using the geometrical arrangements described.

It is an object of the present invention to provide a bistable magnetic actuator which is controllable with respect to at least some of the parameters such as speed of stroke, force of stroke, acceleration and deceleration profile of stroke.

In accordance with one aspect of the present invention there is provided a bistable magnetic actuator comprising: an armature moveable between a first bistable position in which it completes a first permanent magnetic flux circuit and a second bistable position in which it completes a second permanent magnet flux circuit; a first driving coil adapted to cause the armature to move from the first to the second bistable position when the coil is energised; a second driving coil adapted to cause the armature to move from the second to the first bistable position when the coil is energised; and first control means adapted to energise a coil as a first braking coil, during at least part of the period when the first driving coil is being energised to cause the armature to move from the first to the second bistable position.

In accordance with a second aspect of the present invention there is provided a method of driving an armature in a bistable magnetic actuator comprising a first driving coil adapted to cause the armature to overcome a permanent magnet holding force and move from the first to the second bistable position when the coil is energised and a second driving coil adapted to cause the armature to overcome a permanent magnet holding force and move from the second to the first bistable position when the coil is energised, the method comprising the steps of: energising the first driving coil for a first period to cause the armature to move from the first to the second bistable position; and energising a first braking coil, during at least part of the first period, to vary

either the time at which the armature commences movement, or the velocity at which the armature moves.

The present invention will now be described in detail by way of example, and with reference to the accompanying drawings in which:

Figure 1 shows a perspective view of a prior art magnetic actuator with one coil and yoke laminations removed to reveal internal components;

Figure 2 shows an end view of a centre cross-section of the complete prior art actuator of figure 1;

Figure 3 shows a schematic diagram of a circuit according to one embodiment of the present invention; and

Figure 4 shows a detailed circuit diagram of a circuit according to one embodiment of the present invention.

With reference to figures 1 and 2, which have already been discussed in some detail, the method of switching the actuator is to provide a current pulse to coil 60 in order for the actuator to flip the armature 40 to the upward position. For the reverse situation, the coil 62 is provided with a current pulse to flip the armature 40 back to the lower position. The current pulse provided must be sufficient to overcome the holding force provided by the permanent magnet flux which retains the armature in a bistable position. During pulsing of coil 60, or coil 62, the other coil remains dormant.

The velocity at which the armature 40 moves is affected by many factors: eg. the shape and configuration of the yokes 12, 19, 20 and magnets 30, the shape and mass of the armature 40 and actuator rod 42, the permeability of the materials used, the coil characteristics etc. Each of these will be characteristic to a specific actuator, and not variable. In addition, the velocity will be dependent upon the load placed on the actuator by the circuit breaker to which it is attached.

In accordance with the present invention, it has been recognized that the presence of the second coil (the non-driving coil, in either case) may be used to advantageously provide a velocity or timing control function which is complementary to the driving coil, and further, can be used to "customise" an actuator to a particular application.

Careful control of a braking force applied by pulsing a braking current to coil 62 enables a modification to the performance characteristic provided by the driving coil 60. By timing and controlling the power level applied through braking coil 62, it is possible to effect one or more of the following:

i) to reduce the velocity of the armature throughout the length of its stroke;

ii) to provide a variable velocity of the armature throughout the length of its stroke, ie. to provide a desired acceleration or deceleration profile, or permit a two-phase "slow-fast" or "fast-slow" operation;

iii) to vary the timing of the onset of armature movement after initially providing driving current to the driving coil.

All of these features can be provided by electronic control without requiring any physical modification to the actuator.

With reference to figure 3 there is shown an exemplary control circuit for effecting velocity control on the actuator of figures 1 and 2 or similar.

In the position shown in figure 2, coil 60 is the driving coil, and coil 62 is the braking coil. Coils 60 and 62 both have one terminal coupled to power source +V and the other terminal to respective sides of a single-pole, double

throw switch 100. The common terminal 101 of the switch 100 is coupled to ground. To actuate the actuator 10, switch 100 is thrown to the left hand terminal 102. This action provides a current flow in coil 60, and after a time of the order of a few milliseconds, sufficient magnetic flux is generated to move the armature to its upward position, thereby switching the actuator 10.

However, simultaneously with energising coil 60, the action of switch 100 causes the voltage (approximately +V) on signal line 105 to be pulled down close to ground. Resistors R1 and R2 are chosen to have a high series resistance compared with coil 60 and thus when coil 60 is not energised, +V is divided across coil 60, R1 and R2 with signal line 105 maintained close to +V. Typical values of both R1 and R2 would be of the order of 1MΩ. Operational amplifier 110 has an inverting input 106 which is thereby maintained at a positive voltage slightly greater than its non-inverting input 107. Upon energising coil 60, operational amplifier 110 input voltage 106 drops to close to ground causing op amp output 112 to switch on.

This op amp output signal 112 acts as a trigger which may be used in a number of ways. In the embodiment shown, the signal is supplied to a timer / control unit 120 via an optical isolator 115 of known type. Optical isolation is provided to protect the electronic circuitry of the timer 120 from any high voltages produced by the inductance of coils 60, 62.

The timer / control unit 120 may be pre-programmed with an on-time and an off-time via preset switches 121,122 respectively. Upon receipt of the trigger signal from op amp output 112, a first counter times a first time period according to on-time switch 121 before timer output 125 is asserted, and a second counter times a second, longer, time period according to off-time

switch 122 before de-asserting timer output 125. Timer output 125 is fed through a further optical isolator 115a to a solid state switch 130 which energises braking coil 62 for the time that timer output 125 is asserted.

The control of the energising of braking coil 62 can be achieved with an accuracy of fractions of a microsecond. Bearing in mind that the time period between energising driving coil 60 and actual movement of the armature is of the order of a few milliseconds, this allows considerable scope for influencing the movement of the armature 40. The magnitude of the braking current applied to braking coil 62 is controllable by varying resistor 131.

Where the onset of timer output signal is programmed to occur prior to movement of the armature 40, it has the effect of delaying the movement of the armature, since it becomes necessary for the driving coil 62 to overcome the holding force provided by the permanent magnet flux, but also that additionally being provided by the braking coil 62.

Where the onset of timer output signal is programmed to occur immediately after armature 40 has commenced movement, and is maintained during the movement, the effect is to slow down the movement of the armature throughout its stroke.

Where the onset of timer output signal is programmed to occur immediately after armature 40 has commenced movement, and is maintained only for a first portion of the armature movement, the effect is to slow down the first portion of its stroke, but not the second.

It will be understood that various combinations of these effects can be used to vary the effect of the braking coil to produce a large number of possible variations in the armature stroke velocity and force.

It will be understood that the circuit of figure 3 shows only the control circuitry for operating coil 62 as a braking coil. However, replication of the braking circuitry for coil 60 in appropriate manner would enable the coil 60 also to be used in the capacity of braking coil.

Figure 4 shows a detailed circuit diagram of a velocity control circuit according to the principle described in relation to figure 3.

More complex, multi-phase strokes would require a more complex timing mechanism.

In the embodiment described in connection with figure 3, the trigger signal for the braking coil 62 is provided by monitoring the onset of current supplied to the driving coil 60. The trigger signal may also be provided by way of a capacitive or magnetic proximity switch of known type coupled to detect the onset of movement of the armature 40 within the yoke 12.

In a preferred embodiment, the timer unit 120 is programmable with any desired timing intervals to suit the application, and the particular type of actuator in use. Timer 120 may also be provided with a memory storing a look-up table of on and off times to suit different applications, triggered by different control inputs.

In a further embodiment, the actuator may be provided with a third coil (not shown) with which to effect velocity control opposing one or both the other driving coils.

A substantial advantage of the actuator described above is that the timer control unit 120 operates considerably faster than the operation of the armature under the influence of the driving coil. This time delay, of the order of milliseconds, in the onset of armature movement enables the timer control unit to make preprogrammed decisions in respect of the timing and power of the braking coil current. A particularly useful application of this is in the control of the precise instant at which an actuator operates to interrupt current flow in a high current circuit. It is desirable to choose to interrupt the current on a high voltage, alternating supply as close as possible to the zero crossing point of current amplitude. For example, in a three-phase system, each of the three phases would typically be provided with a separate circuit breaker, all three of which are controlled by a single trip signal. Thus, even if one circuit breaker was to open at the appropriate time, the other two certainly would not do so.

By providing the timing control circuitry according to the present invention with appropriate current or voltage sensing circuitry, the power applied to the braking coil may be precisely controlled to ensure that each circuit breaker for each phase is operated at exactly the optimum moment, even though only a single initial "trip" signal is used to trigger the circuit breaking process.

Such a system can be designed to fail safe, since loss of timing control or braking coil current will simply result in the actuator operating as a standard prior art actuator as previously described.

It will be understood that although the present invention has been described in relation to a bistable magnetic actuator such as that described in PCT/GB94/01975, it has wider applicability to any permanent magnet bistable actuator having a first and a second driving coil for switching the actuator between first and second bistable positions.

CLAIMS

1. A bistable magnetic actuator comprising:

an armature moveable between a first bistable position in which it completes a first permanent magnet flux circuit and a second bistable position in which it completes a second permanent magnet flux circuit;

a first driving coil adapted to cause the armature to move from the first to the second bistable position when the coil is energised;

a second driving coil adapted to cause the armature to move from the second to the first bistable position when the coil is energised;

first control means adapted to energise a coil as a first braking coil, during at least part of the period when the first driving coil is being energised to cause the armature to move from the first to the second bistable position.

2. A bistable magnetic actuator according to claim 1 wherein the first braking coil is the same coil as the second driving coil.

3. A bistable magnetic actuator according to claim 2 further comprising second control means adapted to energise the first driving coil as a second braking coil, during at least part of the period when the second driving coil is being energised to cause the armature to move from the second to the first bistable position.

4. A bistable magnetic actuator according to any preceding claim wherein the first or second control means is adapted to energise its respective braking coil for at least part of a period prior to actual movement of the armature caused by the respective first or second driving coil.

5. A bistable magnetic actuator according to any preceding claim wherein the first or second control means is adapted to energise its respective braking coil during at least part of a period of movement of the armature caused by the respective first or second driving coil.

6. A bistable magnetic actuator according to claim 5 wherein the first or second control means is adapted to vary the power supplied to the braking coil during the period of movement.

7. A bistable magnetic actuator according to claim 4, coupled to a circuit breaker for interrupting a varying current in a circuit, wherein the first or second control means includes current sensing means in the circuit and is adapted to vary the duration of energisation of the braking coil for a period which ensures that the actuator drives the circuit breaker to interrupt the circuit at a predetermined level of current flow in the circuit.

8. A bistable magnetic actuator and circuit breaker according to claim 7 including a further two linked magnetic actuators and circuit breakers for interrupting current in three circuits in a three phase system, the first actuator including means to convey a signal indicating energisation of its driving coil to third and fourth control means of the other two actuators respectively, which third and fourth control means are adapted to cause the other two circuit breakers to interrupt current at a time having predetermined relation to the signal.

9. A method of driving an armature in a bistable magnetic actuator comprising a first driving coil adapted to cause the armature to overcome a permanent magnet holding force and move from the first to the second bistable position when the coil is energised and a second driving coil adapted to cause the armature to overcome a permanent magnet holding force and move from the second

to the first bistable position when the coil is energised, the method comprising the steps of:

energising the first driving coil for a first period to cause the armature to move from the first to the second bistable position;

energising a first braking coil, during at least part of the first period, to vary either the time at which the armature commences movement, or the velocity at which the armature moves.

10. A method according to claim 9 including the step of configuring the second driving coil to be operable as the first braking coil.

11. A method according to claim 10 including the further steps of:

energising the second driving coil for a second period to cause the armature to move from the second to the first bistable position;

energising a second braking coil, during at least part of the second period, to vary either the time at which the armature commences movement, or the velocity at which the armature moves.

12. A method according to claim 11 including the step of configuring the first driving coil to be operable as the second braking coil.